7. Food Intake

7.1 Introduction

Some of the toxic substances emitted by California facilities such as dioxin and metals can be deposited onto soil, surface water bodies and food crops. Persons consuming garden produce may be exposed to toxic substances directly deposited on the leaves or taken up through the roots. Home raised chickens, cows and pigs may be exposed through consumption of contaminated feed, pasture, soil, water and breathing of contaminated air. Humans may subsequently be exposed through consumption of contaminated meat and milk. In order to quantify the cancer and noncancer risks, the dose must be determined. Dose in this pathway is proportional to consumption rate and the concentration of the toxicant in the produce, meat, or milk. Probability distributions and default consumption rates for homegrown vegetables and fruits, chicken, beef, pork, cow's milk and eggs are discussed in this chapter. Homegrown produce, meat and milk are evaluated in the AB-2588 program because risk to the population surrounding a facility is being evaluated. While a facility could contaminate commercially grown produce, meat and milk, typically commercially-grown products come from diverse sources. Thus the risk to an individual from consuming commercial products contaminated from a single facility is likely to be quite small.

7.2 Algorithm for Food Intake Dose

7.2.1 Point Estimate (Deterministic) Algorithm

$$\text{Dose} = \frac{(Cf * IF * GI * L) * EF * ED\ 1 \times 10^{-6}}{AT} \qquad \text{(Eq. 7-1)}$$

where:

	Dose =	(mg/kg-day)
	Cf =	concentration of toxicant in food type F (μg/kg)
	IF =	consumption (g/kg body weight per day)
	GI =	gastrointestinal absorption factor (unitless)
	L =	fraction of food type consumed from contaminated source (unitless)
	1×10^{-6} =	conversion factor (μg/kg to mg/g) for Cf term
	EF =	exposure frequency (days/year)
	AT =	averaging time, period over which eposure is averaged (days).
	ED =	exposure duration (years)

The gastrointestinal absorption factor is rarely used because the oral reference exposure levels and cancer potency factors are not adjusted for absorption.

7.2.2 Stochastic Algorithm

The algorithm for the stochastic method is the same as the point estimate algorithm. Distributions are substituted for single values.

7.3 Methods and Studies Available for Estimation of Per Capita Consumption

The USDA estimates the amount of food which disappears into the wholesale and retail markets (Putnam and Allshouse, 1992). The amounts exported, non-food uses and other food not available to the general public are subtracted from this total. Per capita consumption is then estimated by dividing by the population of the United States. This methodology fails to account for losses which occur during processing, marketing and home use (Putnam and Allshouse, 1992). Separate regions are not differentiated in these studies. California is more ethnically diverse than the rest of the country, and thus may have different food consumption rates from the average national consumption rates. Significant differences in food consumption patterns between ethnic groups have been documented (Kant et al., 1991). In addition, the different consumption rates of men, women or children cannot be determined with this method. These studies were not used because of these limitations.

The food frequency method asks subjects the frequency with which they consume foods on a checklist of 20 to 100 items over a previous period of time. This methodology has been used to study the relationship between disease and diet and is more successful in measuring intra-individual variability in food consumption than some other methods such as three day recall surveys (Block, 1992). However, food frequency surveys measure a limited number of items compared to other methods. Our desire was to determine consumption rate distributions of various types of vegetables and meats as accurately as possible for the California population. We were unable to find food frequency studies which specifically addressed the ethnically diverse population of California. We therefore chose not to use studies which employed the food frequency methodology.

The National Health and Nutrition Examination Surveys (NHANES) have been conducted by The National Center for Health Statistics periodically since 1971. At the time that OEHHA was deciding which data and studies would be most appropriate to use for food consumption distributions, the latest available results and raw data were from the NHANES II (1976-1980). NHANES II was designed to be representative of the entire United States and the data could not be subsetted in order to extract regional information. OEHHA chose not to use the NHANES II study because of the availability of more recent studies and the impossibility of extracting data specific to California or the Pacific region.

The United States Food and Drug Administration conducted the Nationwide Food Consumption Survey (NFCS) in 1935, 1942, 1948, 1955, 1965-66, 1977-78 and 1987-88. A series of food consumption surveys conducted by USDA in 1985, 1986, 1987, 1989, 1990 and 1991 were called Continuing Surveys of Food Intakes of Individuals (CSFII). The 1965-66, 1977-78, 1987-88 NFCS and the CSFII surveys determined individual food consumption. The earlier NFCSs only determined overall household food consumption. For this reason, and because of the availability of later surveys, these earlier surveys were not used by OEHHA.

The 1977-78 NFCS survey has been extensively used for risk assessment purposes (CalTOX, 1993; U.S. EPA, 1989). It is generally recognized as a well conducted study. We were concerned that current dietary patterns would not be reflected by 1977-78 NFCS and therefore chose to use more recent studies.

The 1985 CSFII surveys collected data on men age 19-50 years old, women 19-50 years old and their children 1-5, and low income women 19-50 and their children 1-5 years old. The 1986 and 1987 surveys collected data on women 19-50 and their children 1-5 years old. OEHHA did not use the 1985, 1986 and 1987 CSFII studies because the individual studies did not cover all segments of the population.

The USDA conducted the National Food Consumption Survey in 1987-88 which covered the entire U.S. population. The 1987-1988 survey has been criticized because of a 34% response rate (GAO, 1991). If a survey with a low response rate is to be used, it is necessary to establish that the non-responding group is not different from the responding group in some important respect. If the non-responders differ in some important respect such as ethnicity or socioeconomic status, the results will be biased. A test for non-response bias was not performed on the data, therefore OEHHA decided to exclude the 1987-1988 surveys from consideration.

The 1989-91 CSFII study surveyed a total of 5,238 individuals including men, women and children. The 1989-91 CSFII survey was designed to be representative of the population of the United States as a whole and a weighting scheme was devised to that end. However, the survey divided the country into various regions; one of the regions is the Pacific region (Washington, Oregon and California). The number of people surveyed in the Pacific region was sufficient so that the region which is dominated by the huge California population could be separately analyzed. OEHHA chose this study to determine food consumption distributions because it was relatively recent, and data specific to the Pacific region could be obtained. OEHHA used the raw data available on computer tape for our analyses.

The survey methodology for the 1989-91 CSFII study is similar to the other USDA food consumption surveys in which information was collected on individual food consumption. The survey used a one-day recall and two-day record administered one time over each of the four seasons. This study is multistage which means that random samples are selected from increasingly smaller groups in the population. The selection process in this study occurs within strata, in this case geographic groups, representing the entire U.S. population. In this type of survey each group, for example Hispanic females, has a known probability of being sampled. In order for the samples to be representative the size of each such group in the population must be determined so that the samples selected are representative of overall population. The sampling results from each group sampled can be weighted based on the group’s proportion of the entire population.

One disadvantage of the CSFII methodology is poor characterization of intra-individual differences. Three days of dietary intake survey may not be sufficient to capture typical intake (Anderson, 1986). This is not a particularly important limitation for the purposes of determining per capita mean intakes. However, the prevalence of low or high intakes may be incorrectly estimated (Anderson, 1986). This may mean that the tails of the food consumption distribution are less accurate. In addition, the estimate of total caloric intake is known to be low, particularly within some groups (Layton, 1993). If consumption levels estimated are underestimated, the health risks posed by the food consumption pathways may be underestimated. However, despite these limitations, this methodology appears to be the best available for our purposes.

OEHHA subsetted the Pacific region data from the CSFII data tapes. The total number of Pacific region subjects in various racial and ethnic categories are listed in Table 7.1. The CSFII sampling strategy was designed so the sample would represent the entire United States instead of the various regions. We wanted to use the Pacific region subset of the data to represent the Pacific region population. Although the proportion of Hispanics in the California population is higher than the proportion of Hispanics in the CSFII data, there is a reasonable proportion of sample population which is Hispanic. Developing an appropriate weighting scheme would have been complicated by the fact that Hispanics fall into the White, Black and “other” racial group categories. The proportion of Blacks in the CSFII sample is also somewhat less than the actual proportion of Blacks in the California population. The weighting scheme presented in the CSFII was not used because it was designed to be representative of the entire United States. The documentation for the CSFII recommends that if the weighting scheme is not used then only one person per household should be selected. OEHHA did not follow this recommendation because the number of subjects would have been too small for our purposes. The use of the data including more than one subject per household is a source of bias. The number of Asians surveyed in the Pacific region was inadequate to represent the Pacific region population. It was therefore decided to pool the surveyed Asians from the entire United States and to use this survey population to represent the Californian Asian population. No significant differences were found between consumption patterns of the surveyed Asians living in the Pacific Region and surveyed Asians living in other regions of the country.

Table 7.1 Pacific Region Sample, Ages 0-70 by Racial Group and Ethnicity

Group	Hispanic	Non Hispanic	Total	% of Total
White	154	677	831	80.3
Black	5	50	55	5.31
Asian/Pacific Islander	0	31	31	3.00
Non Pacific Region Asian/Pac. Islander	0	39	39	3.77
Aleut/Eskimo/American Indian	3	28	31	3.00
Other	42	6	48	4.64
Total	204	831	1,035	100
% of Total	19.6	79.9		

Daily consumption rates, in grams per day, for each individual were determined by summing consumption of each food group, per person, and dividing by the number of days the individual reported consuming the food group. The CSFII survey is quite comprehensive in the range of prepared and non-prepared foods listed. Foods that could only be reasonably obtained from commercial sources were not considered. However, some obviously commercial items for which consumption of home produce equivalent items could be reasonably substituted were included. The list of foods considered is located in Appendix D. The body weight of each individual subject was available as part of the CSFII data. The grams of food per day were divided by body weight in order to express consumption as g/day/kg body weight. Per capita consumption was calculated by multiplying the consumption rate by the ratio of consumers of a particular food group to the total number of participants. Subjects were stratified into two groups, ages 0-9, which is to be used for the 9-year residence time determination, and ages 0-70, which is to be used for both the 30-year and 70-year residence times. Roughly equal numbers of male and female subjects were in the survey.

An estimation of the best parametric model to fit the distributions is done using the fitting function in Crystal Ball® version 4.0 (Tables 7.2 and 7.3). The Anderson Darling criterion is used since this procedure is more sensitive to the tails of the distributions. The following distributions are considered as possible fits for these data: Normal, Triangular, Lognormal, Uniform, Exponential, Weibull, Beta, Gamma, Logistic, Pareto and Extreme Value. In a couple of cases the distributions fit by Crystal Ball® did not fit the tails or mean of the distribution very well. A lognormal distribution generated using the same 10th and 90th percentiles as the empirical data distributions appeared to be a better fit. The type of distribution that fit best is noted in Tables 7.3 and 7.5. Tables comparing the empirical distributions with the parametric models are presented in Appendix C.

7.4 Categorization of Produce

Exposure to radionuclides from produce consumption was considered by Baes et al. (1984). This study determined soil to plant concentration factors for various elements and metals. The physical processes through which plants are contaminated by airborne radionuclides are analogous to the processes through which airborne low volatility chemical contamination may occur. Therefore, OEHHA has chosen a categorization scheme similar to Baes et al. (1984) for the semi-volatile organic and heavy metal toxicants addressed in the AB-2588 program. The one exception to the Baes et al. (1984) scheme is that OEHHA has chosen to place the root vegetables in a separate category.

In the study, produce was divided into different categories based on the manner in which contamination from air deposition occurs. The leafy vegetable category consists of broad-leafed vegetables in which the leaf is the edible part, for example spinach. The vegetables in this category can be contaminated by deposition onto leaf surfaces. The root vegetable category has items that were placed into other categories by Baes et al. (1984). An example of a root crop is potatoes. OEHHA staff used this category for crops for which root translocation could be a source of contamination. The next category is the exposed produce, which is comprised of produce with a small surface area subject to air deposition. An example of exposed produce is strawberries. The last category of produce is protected, which includes items such as nuts in which the edible part is not exposed to air deposition. The produce items from the 1989-1991 CSFII were classified into these four categories. This information is presented in Appendix D.

Table 7.2 Empirical Distributions for Per Capita Food Consumption Among Ages 0-9 (g/kg bw/day).

Category of Food	Cons	Non-Cons	Mean	SD	Skew Ness	Kurt-osis	Min*	p01	p05	p10	P20	p30	p40	p50	p60	p70	p80	p90	p95	p99	Max*
Produce																					
Exposed	88	56	4.16	5.58	2.76	8.79	0.30	0.30	0.59	0.73	0.87	1.19	1.32	1.71	2.58	4.31	6.54	10.0	15.7	30.8	30.8
Leafy	60	84	2.92	3.69	2.56	7.77	0.15	0.15	0.39	0.52	0.75	0.93	1.04	1.29	1.97	2.59	4.86	8.16	10.9	20.0	20.0
Protected	41	103	1.63	2.16	1.82	2.28	0.14	0.14	0.23	0.30	0.34	0.40	0.52	0.60	0.73	1.16	3.04	4.66	6.66	8.21	8.21
Root	95	49	4.08	4.66	1.91	3.62	0.22	0.22	0.57	0.68	0.87	1.11	1.45	1.84	2.93	5.38	6.77	11.3	14.9	23.2	23.2
Meat																					
Beef	64	80	2.24	2.63	1.98	3.82	0.25	0.25	0.37	0.47	0.53	0.63	0.86	1.08	1.34	2.09	4.18	5.96	7.97	12.8	12.8
Chicken	42	102	1.80	1.96	1.47	1.84	0.25	0.25	0.30	0.31	0.40	0.45	0.57	0.72	0.99	3.01	3.41	4.29	4.77	8.32	8.32
Pork	40	104	1.31	1.46	2.17	4.64	0.20	0.20	0.23	0.27	0.33	0.43	0.55	0.73	1.05	1.35	1.88	3.14	5.10	6.50	6.50
Dairy	131	13	12.0~	18.7	3.89	20.6	0.52	0.69	1.00	1.73	2.38	2.88	3.63	5.44	7.83	9.74	13.6	31.2	51.9	78.1	145
Eggs	80	64	3.21	3.61	2.14	5.28	0.27	0.27	0.50	0.59	0.75	1.06	1.25	1.49	2.41	3.56	5.53	8.00	10.3	17.9	17.9

*Indicates sample minimum or maximum
Total of consumers and non-consumers equals 144 in each case. The same 144 subjects are represented in each food category.

Table 7.3 Parametric Models for Ages 0-9 Food Consumption Distributions (g/kg BW/day).

Category of Food	Distribution Type	Mean	Std. Dev.	Location	Scale	Shape	Anderson-Darling Statistic	μ ± σ
Produce								
Exposed	Gamma			0.00	35.79	1.90	0.4703	
Leafy	Lognormal	2.83	3.89				0.7527	exp (0.43±1.03)
Protected	Weibull			0.13	1.21	0.71	1.3865	
Root	Lognormal	4.08	5.91				1.4049	exp (0.84±1.06)
Meat								
Beef	Weibull			0.24	1.72	0.77	1.1036	
Chicken	Gamma			0.25	2.94	0.53	1.0286	
Pork	Weibull			0.18	0.97	0.78	0.2092	
Dairy	Lognormal	11.32	18.3				0.9195	exp (1.78±1.13)
Eggs	Weibull			0.26	2.67	0.82	0.9977	

Table 7.4 Empirical Distributions for Per Capita Food Consumption Among Ages 0-70 (g/kg BW/day).

Category of Food	Cons	Non-Cons	Mean	SD	Skew Ness	Kurt-osis	Min*	P01	p05	p10	p20	P30	p40	p50	p60	p70	p80	p90	p95	p99	Max
Produce																					
Exposed	725	310	3.56	5.12	4.57	31.9	0.05	0.13	0.28	0.44	0.66	0.93	1.42	2.00	2.57	3.53	5.13	7.93	12.1	25.5	59.5
Leafy	624	411	2.90	3.50	2.75	10.1	0.02	0.08	0.24	0.35	0.52	0.82	1.27	1.79	2.36	3.12	4.26	6.68	10.6	16.3	26.6
Protected	364	671	1.39	1.75	3.83	24.2	0.03	0.05	0.13	0.17	0.26	0.42	0.60	0.86	1.22	1.51	2.00	3.01	4.88	8.23	17.7
Root	707	328	3.16	3.81	3.17	16.1	0.03	0.09	0.27	0.41	0.62	0.89	1.40	1.88	2.58	3.51	4.91	7.29	10.5	17.7	34.7
Meat																					
Beef	606	429	2.25	3.07	6.30	70.1	0.04	0.07	0.23	0.32	0.46	0.63	0.91	1.34	1.85	2.43	3.50	5.15	6.97	11.1	44.6
Chicken	416	619	1.46	1.90	3.96	27.1	0.02	0.04	0.12	0.18	0.27	0.38	0.59	0.87	1.19	1.50	2.32	3.24	5.02	8.40	20.4
Pork	376	659	1.39	1.79	3.83	24.7	0.03	0.04	0.12	0.18	0.27	0.37	0.53	0.78	1.14	1.56	2.07	3.20	4.59	8.50	18.3
Dairy	891	144	5.46	8.96	6.33	65.1	0.04	0.16	0.43	0.59	0.95	1.40	2.12	2.87	3.95	5.45	7.58	11.7	17.4	48.0	137
Eggs	521	514	1.80	2.30	4.92	42.1	0.04	0.06	0.19	0.28	0.38	0.55	0.81	1.11	1.55	1.97	2.59	4.06	5.39	9.71	28.7

*Indicates sample minimum or maximum
Total of consumers and non-consumers in each case equals 1035. The same 1035 subjects are represented in each food category.

Table 7.5 Parametric Models for Ages 0-70 Food Consumption Distributions (g/kg bw/day)*

Category of Food	Mean	Std. Dev.	Distribution Type	Anderson-Darling Statistic	$\mu \pm \sigma$
Produce					
Exposed	3.43	6.16	Lognormal	1.11859	exp (0.51±1.20)
Leafy	2.97	4.95	Lognormal	10 ,90 %tile	exp (0.42±1.15)
Protected	1.39	2.43	Lognormal	1.6613	exp (-0.37±1.18)
Root	3.07	5.23	Lognormal	1.9557	exp (0.44±1.17)
Meat					
Beef	2.32	3.50	Lognormal	10,90 %tile	exp (0.25±1.09)
Chicken	1.44	2.19	Lognormal	10, 90%tile	exp (-0.23±1.09)
Pork	1.42	2.30	Lognormal	1.13	exp (-0.29±1.13)
Dairy	5.57	10.5	Lognormal	1.5102	exp (0.96±1.23)
Eggs	1.84	2.60	Lognormal	1.7077	exp (0.061±1.05)

*In three cases (Leafy, Beef and Chicken) the distributions fit by Crystal Ball were judged to be an inadequate fit and a lognormal distribution with the same 10th and 90th percentiles as the empirical distribution were judged to be a better fit.

7.5 Produce, Meat, Dairy and Egg Consumption Distributions

Produce, meat, dairy and egg consumption distributions are presented for ages 0-9 (Table 7.2) and ages 0-70 (Tables 7.4 and 7.5). As previously discussed produce has been divided into leafy, root, exposed and protected. Consumption is expressed in terms of gram/kilogram body weight/day in these tables. For informational purposes, we provide consumption expressed in g/day for the same age groups in Appendix C.

7.6 Calculating Contaminant Concentrations in Food

The previous sections focused on intake rates for a variety of foods, and included development of point estimates and distributions for those intake rates. Intake rates represent one exposure variate in the algorithm, estimating dose through ingestion of foods. In order to calculate human exposure to contaminants through the food chain, as in Eq. 7-1, concentrations of contaminants, Cf, must be estimated in food products. The following sections describe the algorithms and default values for exposure variates used in estimating concentrations in foods.

7.6.1 Algorithms used to Estimate Concentration in Vegetation (Food and Feed)

The concentration of contaminants in plants is a function of both direct deposition and root uptake. These two processes are estimated through the following equations:

$$Cf = (Cdep)\ (GRAF) + Ctrans \qquad \text{(Eq. 7-2)}$$

where:
- Cf = concentration in the food (μg/kg)
- Cdep = concentration due to direct deposition (μg/kg)
- GRAF = gastrointestinal relative absorption fraction
- Ctrans = concentration due to translocation form the roots (μg/kg)

A gastrointestinal relative absorption fraction (GRAF) is included in the calculation of concentration via deposition to account for decreased absorption in the GI tract of materials bound to fly ash or fly ash-like particulate matter relative to absorption of a contaminant added to the diet in an animal feeding study. At the present time, data are only available for polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F), based on the 2,3,7,8-TCDD congener. The GRAF for those compounds is 0.43. All others have a GRAF of 1. There are no data available to describe differential absorption from fly ash particles as compared to feed for other compounds. Consequently, the factor comes into play only in calculating dose of PCDD/F through this pathway. Note that the factor is not applied to the material translocated through the roots, as this is assumed to be absorbed to the same extent as that in the feed of the experimental animals in the study which is the basis for both the cancer potency factor and reference exposure level.

7.6.1.1 Deposition onto Crops

The factor Cdep is calculated by the following equation:

$$Cdep = [(Dep)\ (IF)/(k)\ (Y)] \times (1-e^{-kT}) \qquad \text{(Eq. 7-3)}$$

where:
- Dep = deposition rate on impacted vegetation ($\mu g/m^2$/day)
- IF = interception fraction
- k = weathering constant (d^{-1})
- Y = crop yield (kg/m^2)
- T = growth period (days)

The variate, Dep, is a function of the modeled (or measured) ground level concentration, and the vertical rate of deposition of emitted materials, and is calculated as follows:

$$Dep = GLC \times Dep\ rate \times 86{,}400 \qquad \text{(Eq. 7-4)}$$

where:
- GLC = ground level concentration of contaminant in air (g/m^3)
- Dep-rate = vertical deposition rate (m/sec)
- 86,400 = seconds per day

The ground level concentration is calculated in the air dispersion modeling (see Section 2). The deposition rate is assumed to be 0.02 meters per second for a controlled source and 0.05 meters/second for an uncontrolled source (see Section 2).

The interception fraction in Eq. 7-3 above is crop specific. The work of Baes et al. (1984), examining the transport of radionuclides through agriculture, describes interception fraction as a factor which accounts for the fact that not all airborne material depositing in a given area initially deposits on edible vegetation surfaces. That fraction will be somewhere between zero and one. Some information is available from studies of radioactive isotopes for pasture grasses. The empirical relationship for grasses is given by:

$$IFpg = 1-e^{-2.88\ Y} \qquad \text{(Eq. 7-5)}$$

where: IFpg = interception fraction for pasture grasses
Y = yield in kg/m^2 (dry)

Assuming that the wet yield is 2 kg/m^2, and 80% of the wet weight is water, then the IF for pasture grasses is approximately 0.7 (Baes et al., 1984). It is difficult to arrive at a wet yield value for exposed, protected, leafy and root vegetables. It is therefore recommended that the 2 kg/m^2 value be used for these categories of produce as well. There are no data on interception fraction for leafy vegetables and exposed produce. The interception fraction for leafy vegetables and exposed produce were modeled by Baes et al. (1984) using assumptions based on typical methods of cultivating leafy and exposed vegetables in the United States. Baes et al. arrive at an average interception fraction of 0.15 for leafy vegetables (which we round up to 0.2) and 0.052 for exposed produce (which we round up to 0.1).

Additional default values for variates in Eq. 7-3 are obtained from *Multi-pathway Health Risk Assessment Parameters Guidance Document* prepared for South Coast Air Quality Management District (Clement Associates, 1988).

The weathering constant, k, is based on experimental observations from studies of particulate radionuclides on plant surfaces. This weathering constant does not include volatilization from the leaf surface since the radionuclides used were not volatile, nor does it include biotransformation or chemical transformation on the leaf surface. Baes et al. (1984) describe particulate half-lives ranging from 2.8 to 34 days with a geometric mean of 10 days for radionuclides depositing on plants. U.S. NRC uses a weathering constant of 14 d^{-1}. OEHHA proposes using a weathering constant of 10 days based on Baes et al. (1984).

The growth period, T, in Equation 7-3 above is based on the time from planting to harvest. OEHHA recommends a value of 45 days for leafy and root crops and 90 days for exposed and protected fruit (time from fruit set to harvest). The assumptions in the interception fraction include the issue of increasing surface area with growth. Therefore, no additional adjustment is necessary.

7.6.1.2 Translocation from the Roots

The other half of Equation 7-2 represents the amount of contaminant that gets into the plant through root translocation from the soil. The equation for calculating concentration in the plant from root uptake is as follows:

$$Ctrans = Cs\ (UF) \qquad \text{(Eq. 7-6)}$$

where: Cs = concentration in the soil (see Section 4)
UF = root uptake factor

The concentration in the soil is calculated as in Section 6, Equation 6.2, using an assumption of 15 cm mixing depth for the food ingestion pathway. This assumption is based on the fact that vegetable gardens and commercial operations till the soil turning the uppermost layers in and mixing the soil. There are some studies examining root uptake of contaminants from soil into crop plants. Some of these studies are useful in generating root uptake factors to estimate concentration in the edible portions of plants. Baes et al. present soil-to-plant elemental transfer coefficients for a number of elements derived from an analysis of studies in the literature, comparison with other elements from the same group, and comparison of observed and predicted concentrations in plants grown in soils with known concentrations. Where multiple references were available describing transfer coefficients for the same element, Baes and colleagues (1984) calculated the geometric mean. These transfer coefficients were calculated as the ratio of the element in dry plant tissue to the concentration in dry soil. The transfer coefficients were analyzed for vegetative portions of the plant (aerial portions except for reproductive tissue) and for reproductive or tuberous portions separately. These transfer coefficients were adjusted for wet weight of plant parts and wet weight of soil by Clement Associates (1988) for use with food consumption information that is reported on a wet weight basis. Clement Associates (1988) assumed a dry-to-wet weight fraction of 0.08 for leafy crops, 0.126 for exposed crops, 0.2 for root crops, and 0.8 for soil. We are recommending the numbers in Baes et al. (1984) adjusted as described in Clement Associates (1988) for use as plant uptake factors in Equation 7-6 (Table 7.6).

Table 7.6 Soil uptake factors for inorganics based on Baes et al. (1984) soil-to-plant transfer coefficients and adjusted for wet weight as in Clement Associates (1988).

Element	Soil UF Leafy	Soil UF Exposed & Protected	Soil UF Root
Arsenic	4×10^{-3}	9×10^{-4}	4×10^{-4}
Beryllium	1×10^{-3}	2×10^{-4}	2×10^{-3}
Cadmium	6×10^{-2}	2×10^{-2}	4×10^{-2}
Chromium	8×10^{-4}	7×10^{-4}	1×10^{-3}
Lead	5×10^{-3}	1×10^{-3}	2×10^{-3}
Mercury	9×10^{-2}	3×10^{-2}	5×10^{-2}
Nickel	6×10^{-3}	9×10^{-3}	2×10^{-2}

UF leafy = uptake factor for leafy vegetables; derived from Baes et al. (1984) as follows:
$Bv \times 0.08/0.8$, where Bv is the soil-to-plant transfer factor for vegetative parts (leaf, stem)

UF exposed = uptake factor for exposed or protected produce; derived from Baes et al. as follows:
$Br \times 0.126/0.8$, where Br is the soil-to-plant transfer coefficient for reproductive or tuberous plant parts.

UF root = uptake factor for root crops; derived from Baes et al. as follows:
$Br \times 0.2/0.8$ where Br is the soil-to-plant transfer coefficient for reproductive or tuberous plant parts.

7.6.2 Algorithms used to Estimate Dose to the Food Animal

The general formula for estimating concentrations of contaminants in animal products is as follows:

$$Cfa = [Dinh + Dwi + Dfeed + Dpast + Dsi] \times Tco \qquad \text{(Eq. 7-7)}$$

where:
- Dinh = dose through inhalation (µg/day)
- Dwi = dose through water ingestion (µg/day)
- Dfeed = dose through feed ingestion (µg/day)
- Dpast = dose through pasturing/grazing (µg/day)
- Dsi = dose through soil ingestion (µg/day)
- Tco = transfer coefficient from ingested media to meat/milk products

7.6.2.1 Dose via Inhalation

The dose via inhalation is proportional to the concentration of the contaminant in the air and the amount of air breathed in a single day. Note that no attempt is made to account for absorption across the lung. This is in part due to the fact that the cancer potency factors and

Reference Exposure Levels have not been adjusted for absorption. It would not be justifiable to adjust the environmental dose if the toxicity criteria do not reflect absorbed dose. The dose via inhalation is calculated as follows:

$$Dinh = BR \times GLC \quad \text{(Eq.7-8)}$$

where:
- Dinh = dose to the animal via inhalation (μg/day)
- BR = daily breathing rate of the animal (m^3/day)
- GLC = ground level concentration (μg/m^3)

7.6.2.2 Dose via Water Ingestion

Airborne contaminants depositing in surface water sources of drinking water for food animals can end up in the human food chain. The dose to the food animal from water ingestion is proportional to the concentration of the contaminant in the drinking water and the amount of water ingested daily. In addition, the fraction of the water ingested daily that comes from a contaminated body of water is used to adjust the dose to the food animal. That fraction is a site-specific value that must be estimated through survey of the cattle farmers in the impacted area. The dose via water ingestion can be calculated as follows:

$$Dwi = WI \times Cw \times Fr \quad \text{(Eq. 7-9)}$$

where:
- Dwi = dose to the food animal through water ingestion (μg/day)
- WI = water ingestion rate (L/day)
- Cw = concentration of contaminant (μg/L)
- Fr = fraction of animals' water intake from the impacted source

Cw is calculated as in Section 8. Water ingestion rates for food animals are shown in Table 7.7. The fraction of the animals' water intake that comes from the source impacted by emissions is a site-specific variable.

7.6.2.3 Dose from Feed Ingestion, Pasturing and Grazing

Airborne contaminants may deposit on pastureland and on fields growing feed for animals. Deposited contaminant contributes to the total burden of contaminants in the meat and milk. The dose to the animal from feed and pasture/grazing can be calculated as follows:

$$Dfeed = (1\text{-}G) \times FI \times L \times Cf \quad \text{(Eq. 7-10)}$$

where:
- Dfeed = dose through feed ingestion (μg/day)
- G = fraction of diet provided by grazing
- FI = feed ingestion rate (kg/d)
- L = fraction of feed that is locally grown and impacted by facility emissions
- Cf = concentration of contaminant in feed (μg/kg) (calculated in Eq. 7-2)

$$\text{Dpast} = G \times Cf \times FI \qquad \text{(Eq. 7-11)}$$

where:
Dpast = dose from pasture grazing (μg/day)
G = fraction of diet provided by grazing
FI = food ingestion rate (kg/day)
Cf = concentration of contaminant in pasture (μg/kg)

Feed ingestion rates are given for food animals in Table 7.7. The percent of the diet that comes from pasture and feed, and the fraction of feed that is locally grown and impacted by emissions are site-specific variables and values for these variables need to be assessed by surveying farmers in the impacted area. Concentration in the feed and pasture are calculated as in Equations 7-10 and 7-11 above. It is considered likely that feed will come from sources not subject to contamination from the stationary source under evaluation.

Table 7.7 Point Estimates for Animal Pathway

Parameter	Beef Cattle	Lactating Dairy Cattle	Pigs	Poultry
BW (body weight in kg)	500	500	60	2
BR (inhalation rate in m^3/d)	100	100	7	0.4
WI (water ingestion in kg/d)	40	80	8	0.2
FI (feed ingestion in kg/d)	8	16	2	0.1
%Sf (soil fraction of feed)	0.01	0.01	NA	NA
%Sp (soil fraction of pasture)	0.05	0.05	0.04	0.02

7.6.2.4 Transfer Coefficients from Feed to Animal Products

Meat and milk products become contaminated when food-animals inhale or ingest materials that are transferred to the meat or milk. The transfer coefficients presented in Tables 7.8 and 7.9 are taken largely from Clement Associates (1988). This document cites the work of Baes et al. and Ng and colleagues on the transfer of radionuclides through the forage-meat pathway, and uses the equations of Travis and Arms (1988) for calculating transfer coefficients for organic compounds.

Table 7.8 Feed-to-Meat Transfer Coefficients modified from Clement Associates (1988)

Chemical	Form	Tco (d/kg)	Source
Arsenic	NS	2.0×10^{-3}	Baes et al., 1984
Beryllium	NS	1.0×10^{-3}	Baes et al., 1984
Cadmium	NS	5.5×10^{-4}	Baes et al., 1984
Chromium VI	NS	9.2×10^{-3}	Ng et al., 1982
Lead	NS	4.0×10^{-4}	Ng et al., 1982
Mercury [a]	NS	2.7×10^{-2}	Ng et al., 1982
Nickel	NS	2.0×10^{-3}	Ng et al., 1982
PCBs [b]	Aroclor 1254	5.0×10^{-2}	Fries et al., 1973
PCDD/F as 2,3,7,8-TCDD[c]	--	4.0×10^{-1}	Jensen et al., 1981
PAH as benzo-a-pyrene	--	3.4×10^{-2}	OEHHA based on Travis and Arms, 1988

a. Based on observation in chickens.
b. Transfer coefficient derived from feeding study of Aroclor 1254; calculated from concentrations of Aroclor 1254 in milk fat.
c. Transfer coefficient derived from feeding study of 2,3,7,8-TCDD; calculated from a pharmacokinetic extrapolation of 2,3,7,8,-TCDD in beef fat at steady-state.
NS = form of chemical not specified.

Table 7.9 Feed-to-Milk Transfer Coefficients from Clement (1988)

Chemical	Form	Tco (d/L)	Source
Arsenic	sodium arsenate	6.2×10^{-5}	Ng et al., 1979
Beryllium	beryllium chloride	9.1×10^{-7}	Ng et al., 1979
Cadmium	NS	1.0×10^{-3}	Ng et al., 1979
Chromium VI	sodium chromate	1.0×10^{-5}	Van Bruwaene et al., 1984
Lead	NS	2.6×10^{-4}	Ng et al., 1979
Mercury	Mercuric nitrate	9.7×10^{-6}	Ng et al., 1977
Nickel	NS	1.0×10^{-3}	Ng et al., 1979
PCBs [a]	Aroclor 1254	1.0×10^{-2}	Fries et al., 1973
PCDD/F as 2,3,7,8-TCDD [b,c]	--	4.0×10^{-2}	Jensen et al., 1981
PAHs as benzo-a-pyrene [d]	--	1.6×10^{-2}	Travis and Arms, 1988

a. Transfer coefficient derived from a feeding study of Aroclor 1254, calculated from measured Aroclor 1254 in milk fat.
b. Transfer coefficient derived from a feeding study; calculated form a pharmacokinetic extrapolation of 2,3,7,8-TCDD concentration in beef fat at steady state.
c. Transfer coefficient is an average of three values.
d. Transfer coefficient calculated from regression equation in Travis and Arms (1988).
NS = chemical form not specified.

The concentration of contaminant in meat, milk, or eggs can be related to the total mass of the material ingested or inhaled per day. The transfer coefficient represents the ratio of the chemical concentration in meat, milk, and eggs to the mass of the chemical consumed. A basic formula for calculating transfer coefficient for radionuclides is taken from Ng et al. (1979) who studied the transfer of radionuclides through the meat and milk pathway:

$$TCo = \frac{Cm}{(Cf)\,(I)} \qquad \text{(Eq. 7-12)}$$

where:
- TCo = the transfer coefficient from feed to animal meat, milk, or fat in day/kg or day/L;
- Cm = chemical concentration in animal meat, milk, or fat (mg/kg or mg/L)
- Cf = chemical concentration in feed (mg/kg);
- I = reported daily intake of animal feed (kg/day)

In the ideal world, transfer coefficients would be obtained from animal feeding studies under steady-state conditions. However, there are few such studies available in the literature. Some information for inorganic chemicals can be obtained by extrapolating from work done with radionuclides, assuming that the transfer coefficient of the non-radioactive isotope of a compound is the same as the radioactive isotopes. There are studies on transfer of 2,3,7,8-tetrachlorodibenzo-p-dioxin in feed to beef and milk (Jensen et al., 1981; Jensen and Hummel, 1982), and another on transfer of PCBs (Fries et al., 1973). Transfer coefficients from these studies were presented by Clement Associates (1988). Travis and Arms (1988) published a regression equation based on octanol: water partition coefficient for transfer of organic chemicals from feed to animal products. The regression equation for transfer coefficient for feed to meat is:

$$TCo = 10^{-7.6+\log Kow} \qquad \text{(Eq. 7-13)}$$

where:
- TCo = feed to meat transfer assuming a fat content of 25%
- Kow = octanol:water partition coefficient

The regression equation for feed to milk transfer is:

$$TCo = 10^{-8.1+\log Kow} \qquad \text{(Eq. 7-14)}$$

and is based on an assumption of 4% milk fat.

These equations were utilized by Clement Associates (1988) in their calculations of transfer coefficients for a few organic chemicals. The authors of the Clement document adjusted the regression equations of Travis and Arms for a 17% beef fat content after cooking to obtain their feed to meat transfer by multiplying the Travis and Arms regression equation by (0.17/0.25). OEHHA has similarly calculated transfer coefficients for PAHs as benzo-a-pyrene and presented them in Tables 7.8 and 7.9, using a log Kow of 6.3.

In equation 7-12, the dose via various exposure pathways is multiplied by the transfer coefficients. OEHHA recommends that the feed-to-beef transfer coefficients be used for chicken and pork as well. In addition, these transfer coefficients should be used for feed-to-egg transfer. There is a lack of information on the latter, but the composition of eggs (high protein and fat) is similar to meat, and transfer coefficients might also be similar. Another assumption made in Eq. 7-12 is that the feed-to meat and feed-to milk transfer coefficients are also applicable to soil ingestion, water ingestion, pasturing and grazing, and inhalation. Given any data to the contrary, OEHHA is recommending that the feed-to-beef and feed-to-milk transfer coefficients be used for these other exposure pathways.

7.7 Default Values for Calculation of Food Contaminant Concentration

7.7.1 Body Weight Defaults

Reported body weights for dairy cattle have ranged from 350 to 800 kg for adult cows on a maintenance diet, with bulls reaching 900-1000 kg (National Research Council, 1966). Beef cattle have body weights in the range of 181 to 816 kg. Reports of body weight of shorthorn cattle have ranged from 79-359 kg (Johnson et al., 1958) to 568-620 kg (Balch et al., 1953). A default body weight value of 500 kg was established as a reasonable estimate within this range of reported values for both of these types of cattle.

Mean pig body weights of 30.9-80 kg at age 13-23 weeks have been reported (Agricultural Research Council, London, 1967). Mean pig body weights of 56.7-102.1 kg for meat-type pigs and 34-102 kg for bacon-type pigs have also been reported (National Research Council, 1964). A default estimate of 60 kg for pig body weight that falls within the reported range was established.

Mean body weights for chickens have been reported in the range of 1.8-2.5 kg for adult chickens and 0.25-1.5 kg during growth (National Research Council, 1966). A mean body weight of 1.6 kg has been reported for female chickens and male and female chicken body weights of 4.2 kg and 3.4 kg, respectively, were also reported (Sturkie, 1986). A default chicken body weight of 2 kg was selected as a value that falls in the range of those reported in the literature.

7.7.2 Breathing Rate Defaults

Animal breathing rate defaults were calculated based upon a relationship of tidal volume to body weight. Each pound of body weight has been reported to correspond to approximately 2.76 ml of tidal volume (2.76 ml/lb $\cong$ 6.07 ml/kg body weight) (Breazile, 1971). Using this relationship, the default animal body weight, and breathing cycle frequencies also provided in Breazile (1971), breathing rates were generated. Reported breathing frequencies for cattle, pigs, and poultry were 18-28, 8-18, and 15-30 respirations per minute, respectively. The body weight defaults described above were used in the calculations. Use of these values generated a range of breathing rates and the default value was derived as the average of the range limits. Default breathing rates for cattle (both types), pigs, and poultry are 100, 7, and 0.4 m^3/day, respectively. The default value for cattle falls within the range of that reported by Altman et al. (1958).

7.7.3 Feed Ingestion Defaults

Feed intake rates of 4.8-14.1 kg/day and 0.4-15.5 kg/day have been estimated for beef and dairy cattle, respectively (National Research Council, 1964; National Research Council, 1966). Another report estimated feed consumption at 6.1-17.5 kg/day for beef cattle and 15.0-25.0 kg/day for dairy cattle, with means of 12.2 and 16.9 kg/day, respectively (McKone and Ryan, 1989). Feed consumption for a 500 kg dairy cow walking 1 mile/day on a 1.8 Mcal/kg dry matter diet (pasture equivalent) has been estimated at 6.5 kg/day for non-pregnant cows, 11.2 kg/day for pregnant cows, and 15.9 kg/day for lactating cows (Agricultural Research Council, London, 1965). For beef cattle (~400 kg, walking 1 mile/day on a 1.8 Mcal/kg dry matter diet) estimates of feed intake were 6.9 kg/day for maintenance and 8.4-12.3 kg/day for growth diets. For non-lactating beef cattle, a default value of 8 kg/day was established as a value that falls within the reported range. For lactating cattle, the reported value of 16 kg/day was adopted (Agricultural Research Council, London, 1965).

Feed intake for pigs was reported to range from 1.0 to 3.2 kg/day (87% dry matter) for pigs of several types including castrates, gilts and pigs ready for slaughter (Agricultural Research Council, London, 1967). Feed intakes of 3.0-3.5 kg/day for meat-type swine and 0.54-5 kg/day for bacon-type swine have also been reported (National Research Council, 1964). A default value of 2 kg/day was chosen as a reasonable estimate in the range of the reported feed intakes from these literature sources.

Feed ingestion rates for chickens have reported to range from 0.027 to 0.125 kg/day (National Research Council, 1966). Feed rates for growing chickens ranging from 0.040 to 0.130 kg/day have also been reported, with the higher values reported for mature chickens (Wiseman, 1987). A value of 0.1 kg/day was determined as a reasonable point estimate, which falls in the range of the reported values.

7.7.4 Water Ingestion Defaults

Literature reported water intake rates are generally expressed in relation to dry matter ingestion on a weight basis. Water intake also generally increases with increasing temperature. Water intakes of 3.1-5.9 kg/kg dry matter at temperatures ranging from -12°C to 29.4°C have been reported (Winchester and Morris, 1956, as summarized by the Agricultural Research Council, London, 1965). Water intakes of 6.6-10.2 kg/kg dry matter ingested for shorthorn cows at 27°C and 3.2-3.8 kg/kg dry matter ingested at 10°C have been reported (Johnson et al., 1958). Water intake for shorthorn cows at 18-21°C of 4.2-5.0 kg/kg dry matter ingested have also been reported (Balch et al., 1953). Water intake at lower temperatures (-18 to 4°C) of 3.5 kg/kg dry matter ingested has also been reported (MacDonald and Bell, 1958). Friesian cattle water intake was estimated at 3.3-4.3 kg/kg dry matter ingested (Atkeson et al., 1934). Given the feed intake for both non-lactating and lactating cattle as described above, a reasonable default estimate of water consumption is approximately 5-fold the dry matter consumption. The resulting default water consumption rates for beef cattle and lactating dairy cattle are 40 and 80 kg/day, respectively.

Water consumption has been estimated for pigs at 1 kg/day for 15 kg pigs, increasing to 5 kg/day at 90 kg body weight (Agricultural Research Council, London, 1967). Non-pregnant sow water consumption was estimated at 5 kg/day, pregnant sows at 5-8 kg/day, and lactating sows at 15-20 kg/day. A default water consumption estimate of 8 kg/day was chosen to represent an estimate falling in the range of these literature reported values.

Chicken water consumption has been reported to fall in the range of 1-3 times the food consumption on a weight basis (Agricultural Research Council, London, 1975). Two-fold water to feed consumption was established as the default value. Given a daily feed consumption rate of 0.1 kg/day, the resulting daily water consumption rate for chickens is 0.2 kg/day.

7.7.5 Soil Consumption Defaults

Soil consumption was estimated for dairy cattle based upon fecal titanium content (Fries et al., 1982). Among yearling heifers and non-lactating cattle receiving feed (vs. pasture), soil ranged from 0.25 to 3.77% of dry matter consumed, depending on the management system used, with those cattle with access to pasture having the greatest soil consumption. For cattle on feed, a reasonable estimate of 1% soil consumption was made. For cattle grazing pasture, soil intake estimates of 4-8% dry matter consumption have been made for cattle receiving no supplemental feed (Healy, 1968). Soil consumption varies seasonally, with the greatest soil ingestion during times of poor plant growth (14%) and the least soil ingestion during lush growth (2%). In a study of several farms in England, beef and dairy cattle were found to have soil ingestion rates ranging from 0.2 to 17.9% of dry matter consumed, depending both on the location and the time of year (Thornton and Abrahams, 1983). The two largest sets of data evaluated showed a range of soil ingestion of 1.1-4.4% dry matter consumed. A reasonable estimate of soil consumption as percent of pasture consumed is 5%.

Soil consumption estimates have been made for pigs (Healy and Drew, 1970). A mean weekly soil consumption estimate of 1 kg soil/week was made for pigs grazing swedes (rutabaga), corresponding to 0.014 kg soil/day. Other estimates for animals grazing swedes, swedes with hay, and pasture only were 0.084, 0.048, and 0.030 kg soil/day, respectively. Assuming total feed consumption of 2 kg/day, the soil consumption as percent of grazed feed (pasture) ranged from 1.5 to 7%, with a best estimate of 4%. In the absence of information concerning soil content of feed for pigs, no estimate has been made for soil ingestion from feed. For risk assessment purposes, pigs are assumed to consume 4% soil from pasture ingestion.

As a digestive aid, chickens normally consume approximately 2% grit in their diet (McKone, 1993; NRC, 1984). This value was used as an estimate of the fraction of soil consumption for chickens with access to pasture. Chickens were assumed to have access to pasture/soil and therefore, no estimate was made for soil ingestion strictly from feed.

7.8 Summary

OEHHA has used the 1989-91 CSFII survey data for the Pacific region (USDA, 1989-91) to generate per capita consumption distributions for produce, meat (beef, chicken, and pork), dairy products and eggs. The Pacific Region CSFII (1989-91) data used are more representative of the California population than surveys, which address the entire United States. The availability of body weight data for each subject in the survey enabled consumption to be expressed in gram/kg body weight/day. The variability in food consumption that was due to variability in body weight was thus accounted for.

7.9 Recommendations

7.9.1 Point Estimates

OEHHA is recommending that the default values presented in Table 7.10 be used for the point estimate approach (Tiers 1 and 2). These default values represent the mean and 95th percentiles of the distributions presented in Tables 7.2 and 7.4.

Table 7.10 Default Values for Per Capita Food Consumption (g/kilogram /day)*

Category of Food	Ages 0-9		Ages 0-70	
	Average	High End	Average	High End
Produce				
Exposed	4.16	15.7	3.56	12.1
Leafy	2.92	10.9	2.90	10.6
Protected	1.63	6.66	1.39	4.88
Root	4.08	14.9	3.16	10.5
Meat				
Beef	2.24	7.97	2.25	6.97
Chicken	1.80	4.77	1.46	5.02
Pork	1.31	5.10	1.39	4.59
Dairy	12.0	51.9	5.46	17.4
Eggs	3.21	10.3	1.80	5.39

*The average and high end values in this table represent the mean and 95th percentile, respectively, of the distributions in Tables 7.2 and 7.4.

7.9.2 Stochastic Approach

OEHHA is recommending that the food consumption distributions presented in Tables 7.3 and 7.5 be used to assess the risks from consumption of contaminated beef, chicken, pork dairy products and eggs. These parametric distributions are close to the empirical distributions and provide a useful description of the empirical distribution compatible with the use of the currently available software.

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